Journal of Agrometeorology 3(1&2) : 149 -159 (June-December 2001)

Impact of vegetation cover on the ejection and sweep processes in the atmospheric-surface-layer : A case study

J. R. KULKARNI AND L. K. SADANI
Indian Institute of Tropical Meteorology, Pashan, Pune 411008

ABSTRACT

Variation in the statistical characteristics of intermittent ejection, and sweep events with the surface drag and atmospheric stability has been studied using sonic anemometer data at 4 m height in the 'LASPEX-97'. Tall-grass and short-grass surfaces introduced different type of drag conditions leading to roughness differences. Events intermittent in nature were found to depend on surface drag rather than on atmospheric stability and an Intermittency Index is defined. Study of spectral behavior of the events using Haar wavelet transform showed skewed-bell-type distribution, with maximum contribution from the middle scale eddies. Contributions by smaller scale (spatial scales 0.4 - 7.28 m) / larger scales (spatial scales 45.5 m - 3.729 km) eddies were more in smooth / rough surface conditions respectively.

Key words: Land-surface interaction, Ejection-sweep processes, Intermittency of ejection-sweep processes, Wavelet transform.

The exchanges of momentum, heat and moisture at the surface strongly influence the dynamics and thermodynamics of the atmosphere. In order to simulate these by numerical models, a better understanding of the flux processes is required. It is recognized today that these flux processes are not smooth, continuous, but rather composed of discrete, intermittent ejection, sweep events. The studies of Kline *et al.* (1967), Corino and Brodkey (1969), Narhari Rao *et al.* (1971) Brown and Roshko (1974), Kulkarni *et al.* (1999) have brought out the important role played by these events in the maintenance of turbulence. However there are some aspects related to these events for which the understanding is not very clear. One of them is variability of the events with the surface conditions.

As per Monin and Obukhov (1954) similarity theory, and Townsend's (1976) rough-wall similarity hypothesis, outside the roughness sublayer, the turbulent motion is independent of the boundary roughness. In a study Krogstad *et. al.* (1992) revealed that over the rough surface, both these events have a frequency twice of that over a smooth boundary. However, Katul *et. al.* (1997) have shown that ejections and sweeps occurred at equal frequencies irrespective of roughness lengths or atmospheric stability conditions. These contrasting results prompt further studies related to these events under a variety of surface conditions. This study is an attempt in that direction. The variation in the statistical characteristics of these events including intermittency, with the surface drag and atmospheric stability conditions has been

---

E-mail : jrksup@tropmet.res.in

studied.

MATERIALS AND METHODS

Data and turbulent statistics

The Land Surface Process Experiment 1997 (LASPEX -97) was conducted over Sabarmati River basin in the Gujarat State of India. In this experiment, tower data was collected continuously during Intensive Observation Periods (13-18 of every month) at five stations viz. Anand, Sanand, Derol, Khanda and Arnej. For the present study the wind and temperature data at Anand Central station (Lat 22°35' N, Long 72° 55' E) have been used. The experiment site was covered with growing grass (Sun hemp) extending horizontally up to ~ 300 m in East, South, and West directions and ~ 100 m in the North direction. We have selected two days, viz. 13th and 17th August 1997 having contrasting surface conditions. The grass height was different on these two days, being 80-100 cm on 13th (tall-grass condition) and 2-3 cm on 17th August 1997 (short-grass condition). The different grass heights introduced varied drag conditions on the atmospheric surface layer. Eight sets of data, at regular intervals of one hour from 1100 to 1800 hours Indian Standard Time (IST), were collected on these two days. The sampling frequency was 10 Hz, and sampling period was 27.3 minutes (corresponding to 16384 data points). The sonic anemometer (Applied Technologies Inc., SWS-211/3k) at 4 m height, measured the u, v, w components of winds, and air temperatures t. Coordinate transformation was applied to measured wind data to obtain longitudinal (U) and transverse (V) velocity components. The sky was partly cloudy with variable 1 - 4 octa clouds on both the days.

RESULTS AND DISCUSSION

Unstable atmospheric conditions prevailed on both the experimental days. Fig.1(a) shows the variation of the stability parameter z/L (where z is the height of sonic anemometer above the ground and L is Monin-Obukov length). The instability was more on the short-grass-day with a maximum at 1300 hours IST. Fig. 1(b) shows the variation of the drag coefficient C_D, computed as $C_D = (U^* / <U>)^2$ where U^* is wind-friction velocity, on the two experimental days. The drag was found consistently more on the short-grass-day implying the rough surface conditions. At 1300 hours IST, on the short-grass-day, the drag was the maximum and had value twice compared to that on the tall-grass-day at the same observational hour. Relatively high drag values were also observed at 1700 and 1800 hours IST on the short-grass day. Fig. 1(c) shows variation of mean <U> wind at the observational hours on these two days. The wind was stronger on 13th at all the observational hours except at 1500-hour IST. Fig. 1 (d) shows the coefficient of variation for the mean <U> on the two experimental days. In general the variability in the wind speed was more on the short-grass day, reaching as high as 87 % at 1300 hours IST. Fig. 1(e) shows the variation of mean momentum flux. The downward momentum flux was more in the tall-grass condition, at all the observational-hours except at 1500 hours IST. The variation in this flux closely follows the mean wind variation <U>. The upward heat flux in the short-grass condition was consistently more than that in tall-grass condition reaching 185.24 Wm^{-2} at 1500 hour IST (Fig. 1f).

Variation of ejections and sweeps events with surface drag condition

In order to decompose the total flux into

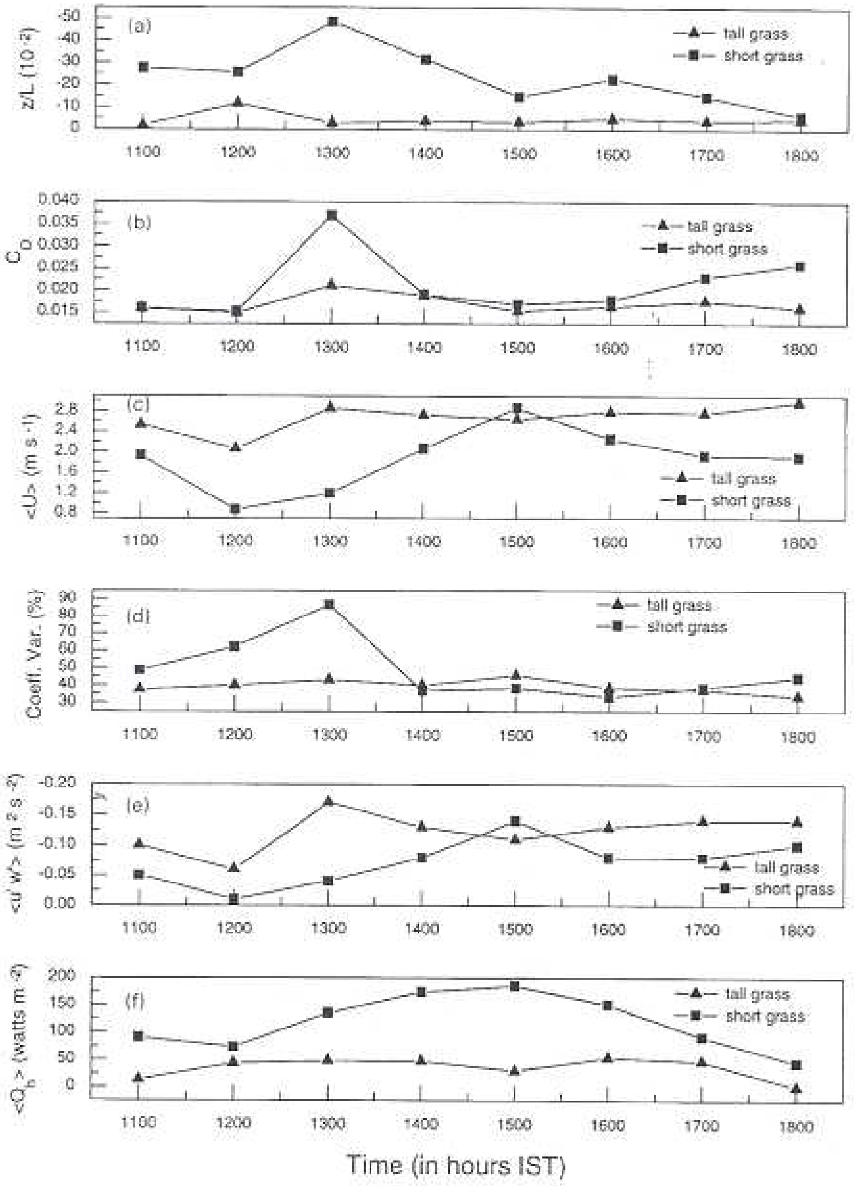

Fig. 1: The variation of (a) z / L (b) CD (c) mean wind <U> (d) coefficient of variation (%) (e) mean momentum flux <u'w'> and heat flux <Qh> at observational hours on 13 August (—▲—) 17 August (—■—) 1997.

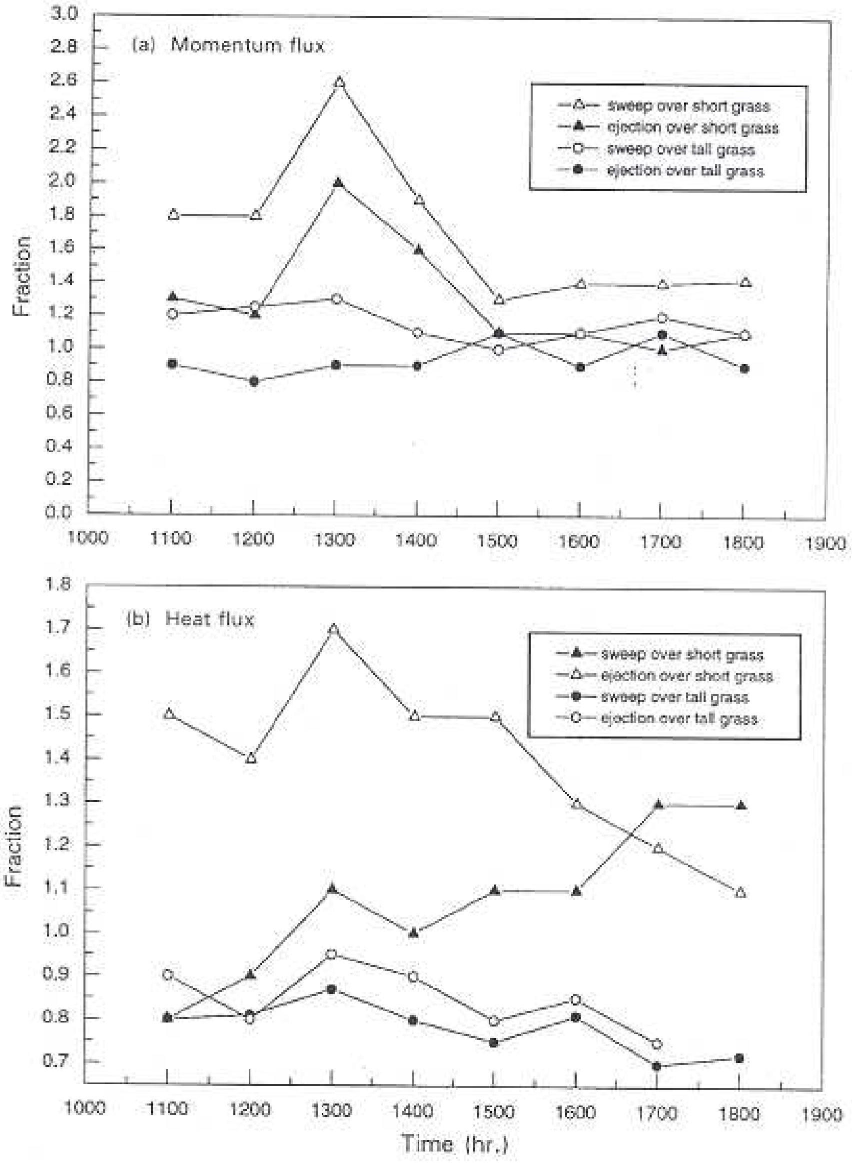

Fig. 2: The fractional variation of sweep and ejection in momentum flux, in the heat flux, for tall grass (13 August) and short grass (17 August)

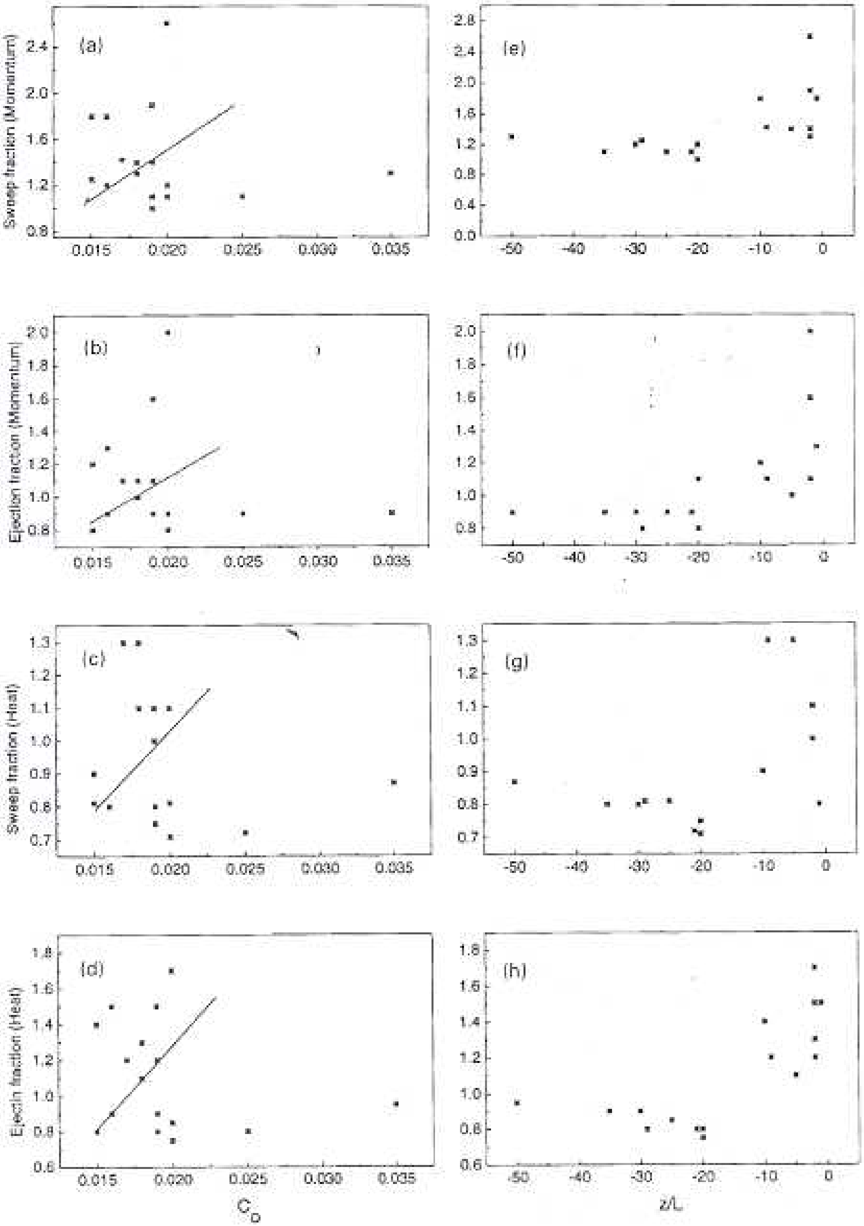

Fig. 3: Variation of (a) sweep fraction (momentum) (b) ejection fraction (momentum) (c) sweep fraction (heat) (d) ejection fraction (heat) with C_D. Figures e, f, g, h are similar to a, b, c, d but for z / L.

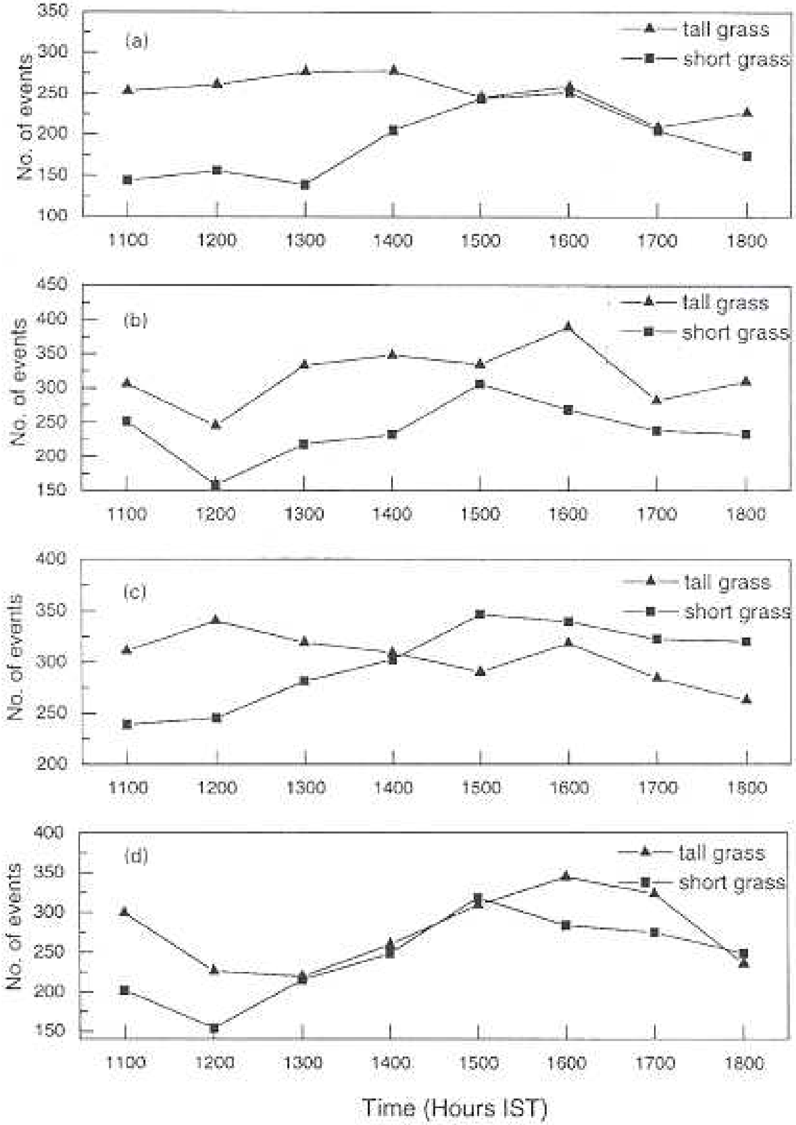

Fig. 4: (a) Variation of number of major ejection events in the tall-grass-condition and in the short-grass-condition with the observational hours in the momentum flux. (b) same as (a) but for sweep events, (c) same as (a) but in the heat flux, (d) same as (b) but in heat flux.

contributions from ejections and sweeps events, the quadrant analysis method (Kulkarni *et al.* 1999) is used. The contributions are expressed in terms of fractions of the total. As the mean flux is a residual of positive and negative values, the fractional contribution at times goes beyond 1. Fig. 2(a) shows the variation of fractional-contributions from ejections and sweeps to momentum flux on the two experimental days. The figure shows that whether grass is short or tall, sweep dominates the contribution to momentum flux, both sweeps and ejections over short grass dominate those over the tall grass.

Fig. 2(b) shows the fractional contribution by these events to sensible heat flux. Here also the behavior similar to that in momentum flux is noticed i.e. the fractional contributions by both these events were more on the short-grass-day. However, here it is the ejection that is predominant in the flux contribution. These results agree with Krogstad *et al.* (1992). The maxima are attained at 1300 hours IST, at which both the instability and drag conditions are also maximum. In order to identify which of these two factors really affected the activity of the fractional-flux-contribution, the variation of these fractional contributions were studied in relation with C_D and z/L. Figs. 3 (a, b, c, d) and (e, f, g, h) show the scatter diagrams of the variation of fractional-contributions by these events with C_D and z/L respectively. It is noticed that a relatively less scatter is seen with C_D compared with z/L.

Intermittency in the events

In the above discussion, all the ejection and sweep events were considered irrespective of their magnitudes. Although the mean momentum and heat flux is the result of innumerable major and minor bursting events, it is observed that the significant contribution (70%) comes from relatively a few major events. In order to isolate the major events, we applied following criterion. In the momentum flux, a major event is said to occur when instantaneous

$U'w' < -\sigma_u \sigma_w$,

similarly in the case of temperature flux, a major event is detected when

$w't' > -\sigma_w \sigma_t$,

where $\sigma_u, \sigma_w, \sigma_t$, are root mean square values of deviations of wind U, w, and temperature t. For the sake of brevity hereinafter a major event is referred as event only. Figure 4 shows the variation of ejection and sweep events on both the experimental days. It is seen from Fig. 4(a, b) that consistently a more number of ejection and sweep events participate in the momentum flux process, in the tall-grass condition than that in the short-grass condition at all the observational hours. In the ejection events a considerable difference is noticed at 1100, 1200, 1300 hour IST. In the case of heat flux process, the roles of ejection and sweep events do not appear to be as distinct as seen in the case of momentum flux process. The ejection in the tall-grass condition was found to be more than that in short-grass condition at 1100, 1200, and 1300 hour IST (Fig. 4 c). More number of sweep events was found in the tall-grass condition than that in the short-grass condition almost at all the observational hours except at 1500 and 1800 hours IST, where they are marginally smaller. Thus it is seen that more number of ejection and sweep events participate in the flux process in the tall-grass condition compared with short-grass condition. This result differs from the result reported by Katul *et al.* (1997)

where in they found the equal frequency of ejection and sweep events in rough and smooth boundary conditions.

Having noticed variation of events with respect to surface conditions, an attempt is made to quantify the intermittency. We defined an intermittency index (II) as

$$II = \left(1 - \frac{support\ \ of\ \ events}{Total\ record\ length}\right)\ X\ 100$$

Here the support of the events means the cumulative record length over which the events are recorded. If the events were present over the entire record length, then, II = 0, and if the events were over short duration, then II would have maximum value. The variation of II with the observational-hours is shown in Figure 5 (a, b). The range of II values is from 57% to 82% in the momentum flux and 57% to 77% in the heat flux events. It is seen that the intermittency is large in the rough surface conditions in both the momentum and heat flux processes. The maximum II is noticed at 1300 hour IST at which both the drag and instability parameter were having maximum values. The analysis using scatter plot (similar to that discussed in the above section) has been carried out to identify which of these is responsible for inducing the intermittency in the events. It was noticed that II was related with the surface drag condition rather than the instability condition.

Spectral nature of the events

In order to understand the dependency of the activity of events on the spatial eddies, the time series of ejection and sweep have been processed by discrete Haar wavelet analysis. The computation of wavelet coefficients and reconstruction are as described in Kulkarni *et al.* (1999). The total number of points used in the study is 16384 ($=2^{14}$), which gives 14 dyadic scales. The turbulent intensity remained less than 0.5 (except at 1300 hours IST in short-grass condition) at all the observational hours. Hence Taylor's (1938) hypothesis was used to convert time increments to space increments. The spatial eddy scales R(a) were computed using

$$R(a) = 2^{m}\ \times <U> / f_s$$

where 'a' is dyadic scale (goes 1-14), and f_s is sampling frequency.The scales of the eddies range from 0.17 m (for scale a =1) at 1200 hours IST on short-grass day to 4.88 km (for scale a = 14) at 1800 hours IST on tall-grass day.

The spectral nature of these events has been shown in Fig. 6(a, b, c, d). One remarkable thing noticed from the figure is that, the spectral distribution has a bell shaped curve, with maximum contribution occurring at the middle scale (spatial scale ~7 ± 2 m) and the decreasing contribution at larger and smaller scales. Another aspect noticed is that the eddies of scales 1 to 5 contribute more in the tall-grass condition and eddies of scales 6-14 contribute in short-grass condition in the activity of events. The mean eddy length for scale 1 is 45.5 cm, for scale 5 is 7.28 m and for scale 14 is 3.729 km. Thus the eddies up to scales 5 i.e. of lengths ~ 5-7 m are active in the tall-grass condition whereas the large eddies extending spatially up to few km are found active in the short-grass condition.

CONCLUSIONS

The study showed that the statistical properties of the ejection and sweep events depend upon the roughness of the surface. The sweep / ejection events play dominant role in the momentum / heat flux processes. The

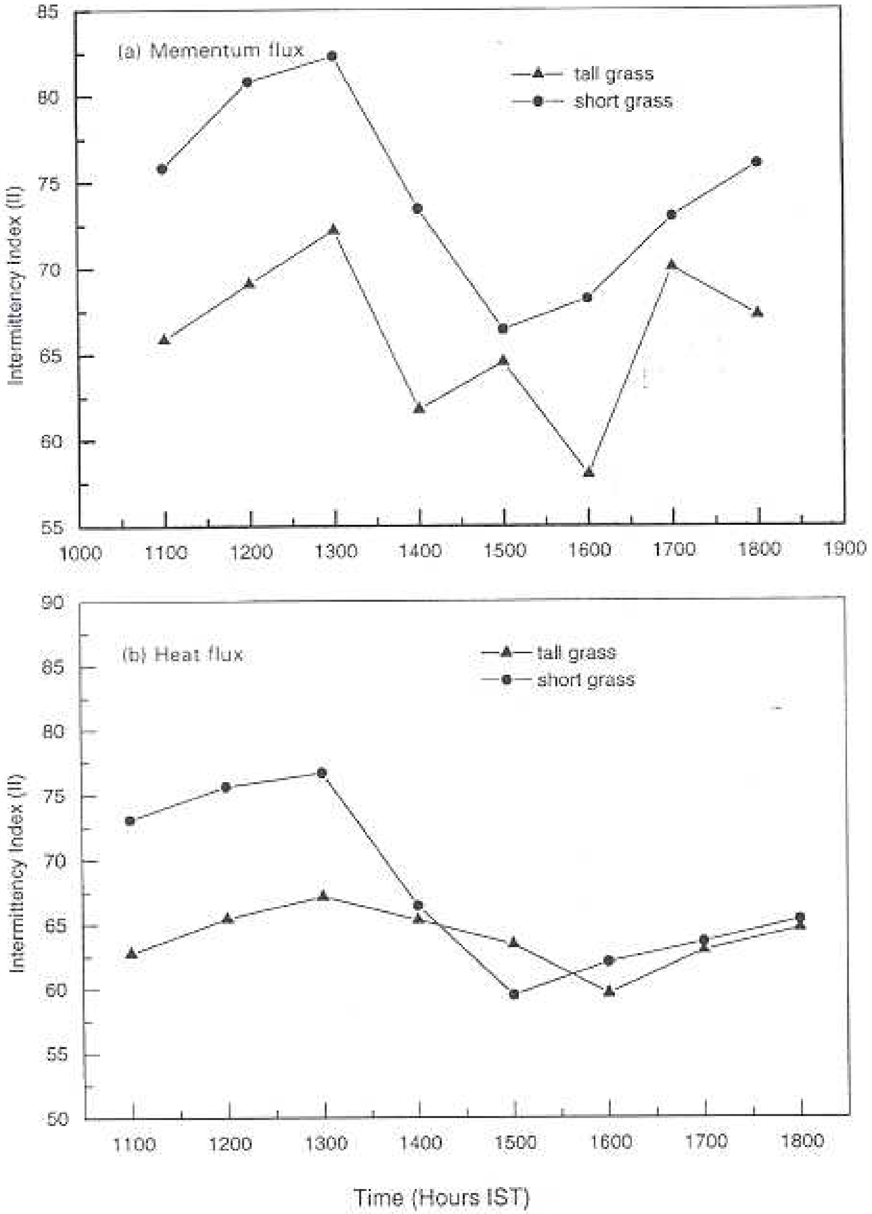

Fig. 5: Variation of intermittency index in the (a) momentum flux and (b) for heat flux in the tall and short-grass conditions with the observational hours.

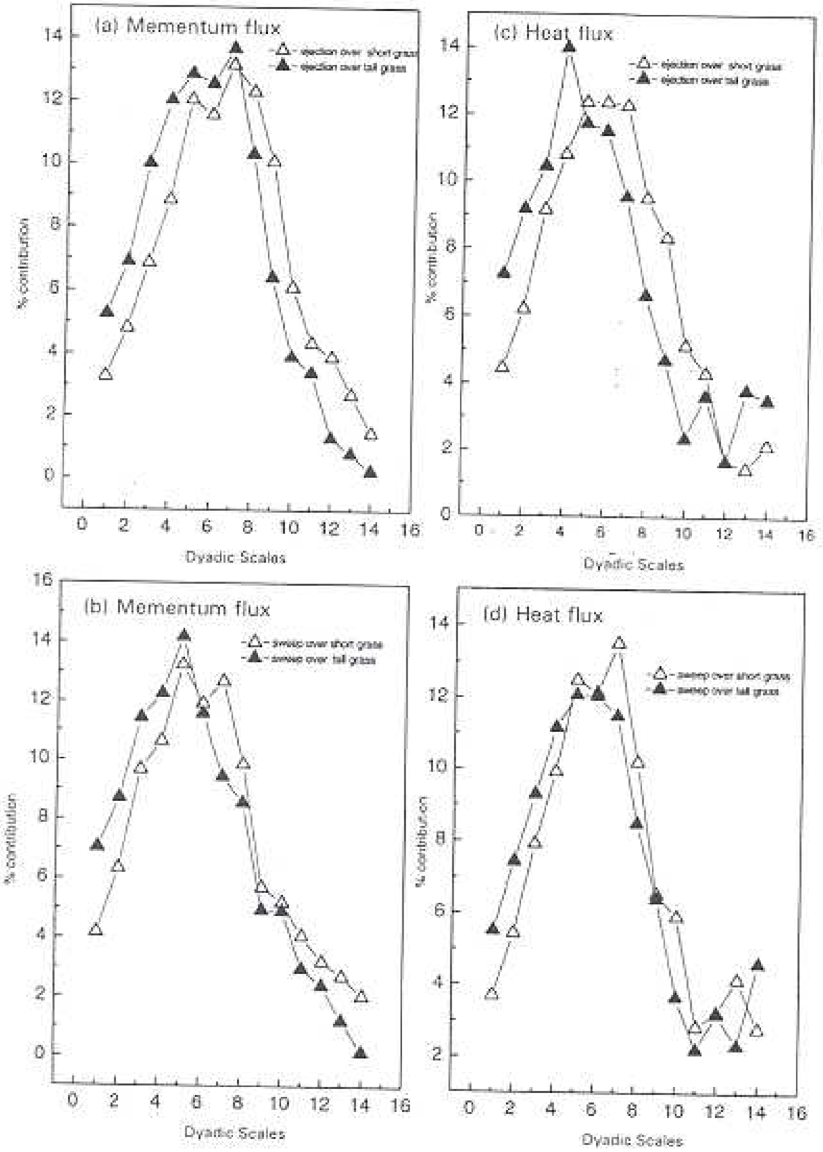

Fig. 6 : Percentage contribution of (a) ejections to momentum flux in the short- grass-condition and in the tall-grass-condition as a function of scale, (b) for sweep, (c) same as (a) but for heat flux and (d) same as (b) but for heat flux.

rough surfaces are found to introduce a large intermittency in these events. The spectral characteristics display a skewed-bell-shaped distribution with the maximum contribution from the middle scale eddy (of scale 6) in the 14 dyadic scale eddy-spectrum. The response of eddies in the ejection and sweep processes depends also on the surface drag conditions. The smaller eddies are more active in the smooth surface condition (tall grass) whereas the large eddies are more active in the rough surface conditions (short grass). These results are based on a single case study. More studies are required for obtaining the universal comprehensive representation of these events.

ACKNOWLEDGEMENTS

The authors would like to thank their colleagues in IITM and GAU who participated in the LASPEX-97 sponsored and supported by the Department of Science and Technology (DST), Government of India, New Delhi. The authors wish to express their thanks to DST.

REFERENCES

Brown, G. L. and Roshko, A. 1974. On Density Effects and Large Structure in Turbulent Mixing Layer. *J. Fluid Mech.*, 64 : 775-816.

Corino, E. R. and Brodekey, R. S. 1969. A Visual Investigation of the Wall region in Turbulent Flows. *J. Fluid Mech.*, 37 : 1-30.

Katul, G., Kuhn, G., Schieldge, J. and Hsieh, C. 1997. The Ejection Sweep Character of Scalar Fluxes in the Unstable Surface Layer. *Bound. Layer Meteteorol.*, 83 : 1-26.

Krogstad, P. A., Antonia, R. A. and Browne, L.W. B. 1992. Comparison between Rough and Smooth Wall Turbulent Boundary Layers. *J. Fluid Mech.*, 245 : 599-617.

Kulkarni, J. R., Sadani, L. K. and Murthy, B. S. 1999. Wavelet analysis of intermittent turbulent transport in the atmospheric surface layer over a monsoon trough region. *Bound. Layer Meteorol.*, 90 : 217-239.

Kline, S. J., Reynolds, W. C., Schraub, F. A., and Rundstadler, P. W. 1967. The Structure of Turbulent Boundary Layers. *J. Fluid Mech.*, 30 : 741-773.

Monin, A. S. and Obukhov, A. M. 1954. Basic Laws of Turbulent Mixing in the Ground layer of the Atmosphere. *Tr. Geofiz Inst. Akad. Nauk. S.S.S.R.*, 151 : 163-187.

Narahari Rao, K. M., Narasimha, R. and Badrinarayana, M. A. 1971. The Bursting Phenomenon in a Turbulent Boundary Layer. *J. Fluid Mech.*, 48 : 339-352.

Townsend, A. A. 1976. The Structure of Turbulent Shear Flow, Cambridge University Press, 428 pp.

Taylor, G. I. 1938. The spectrum of Turbulence. *Proc. Roy. Soc.*, (A) CLXIV: 476-490.